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COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

NATIONAL RESEARCH ON THE QUESTION OF SPACE DEBRIS

Note by the Secretariat

Addendum

The present document contains information provided in replies received from Member States up to 25 February 1992.

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CZECHOSLOVAKIA

[Original: English]

1. Definition of space debris

The meaning of the word "debris" is equivalent to that of "fragments". Its main attribute in our case, is inactive and not serving any purpose anymore. In authoritative studies by the European Space Agency (November 1988), by the Office of Technology Assessment of the United States Congress (September 1990) and by the International Astronautical Federation and COSPAR for the United Nations Committee on the Peaceful Uses of Outer Space (December 1988) the meaning of space debris has been extended to all useless objects in space, irrespective of size. It covers objects of all sizes, from large inactive satellites or burnt out rockets, to freely flying covers, nuts and bolts, down to objects of a fraction of a millimetre, such as flakes of paint. Particles of molecular or atomic sizes are not, in general, referred to as space debris.

An attempt at a precise definition was made at the meeting of the Ad Hoc Group on Space Debris at the IAF Congress in Montreal in 1991:

> "Space debris" or briefly "debris" are all manmade objects launched into space and fragments thereof which will not now or in the future serve a useful purpose. The term includes all such objects which survived the passage through the Earth atmosphere. The term "space debris" does not include natural objects such as meteoroids.

The term "space debris" is sometimes qualified. Thus "orbital debris" refers to debris in orbit, while "re-entering debris" means space debris re-entering the dense layers of the atmosphere or impacting on the ground or on the surface of the ocean. It is conceivable that in the future the term "interplanetary debris" will be used to indicate debris which are not in Earth orbit but in interplanetary space. "Trackable debris" means debris which are large enough to be detected and tracked by present radars and telescopes and which can be attributed to a specific launch. "Non-trackable debris" are debris too small or too infrequently observed to enter the category "trackable". The limiting size of trackable debris depends on the reflecting properties of the surface of the particular object. It is approximately 10 cm in low orbits and 1 m in the geostationary orbit.

Instruments of international law of outer space do not know the term or concept of "space debris". Many references can be found to "space objects" or to "objects launched into outer space" which seem to refer to the same concept. They are not natural objects but man-made. "Space objects" include the "component parts of a space object as well as its launch vehicle and its parts". Officially, the relation between "space objects" in the legal sense and "space debris" in the scientific sense has not been established. Some experts in space law are inclined to count space debris as space objects but

others are of the opinion that space objects have been launched with a certain purpose in mind and that space debris do not fulfil that purpose anymore, and that therefore space debris are not "space objects" in the legal sense. The question thus remains whether or not space debris enjoy the protection of space law, in particular of the Outer Space Treaty, article VIII. According to that article, space objects remain under the jurisdiction and control of the launching country and their ownership is not affected by their presence in outer space, on a celestial body or by their return to Earth. Upon request they have to be returned to the launching country.

2. Format of the discussions

The discussions which inevitably will have to take place soon, will take a course determined by the COPUOS and its Subcommittees. In order just to have one of the possibilities before our eyes and not to omit some important aspect, the following overview may serve the purpose:

1. Preventive measures:

   A. Minimizing the amount of debris produced in operational activities;

   B. Averting unintentional explosions;

   C. Regulating intentional explosions;

   D. Maintaining a certain economy of space missions.

2. Active measures:

   A. Removing inactive objects from low orbits;

   B. Removing inactive objects from orbits at intermediate altitudes;

   C. Removing inactive objects from high orbits;

   D. Removing debris by remote action.

3. Passive measures:

   A. Improving the flow of information on trackable space objects;

   B. Avoiding collisions by evasive manoeuvres;

   C. Shielding of spacecraft.

Preventive measures (1) aim at the causes which produce debris. Simple recommendations by the COPUOS would alleviate the situation. Even if such a recommendation is immediately heeded by designers of spacecraft, an interval

of some 6 to 10 years between the design and the launch will elapse before new spacecraft would produce less operational debris than they do at present.

Causes of explosions of some rocket bodies (1B) have already been discovered and procedures were introduced which prevent such unintentional explosions from occurring. A recommendation by COPUOS would certainly support efforts at avoiding these causes. Intentional explosions (1C), if they are necessary at all, should be performed under conditions producing debris with very short lifetimes. There are examples known of explosions leaving no debris.

The principle that space activities have to be performed for the benefit of all countries could be strengthened from an environment-minding point of view. Space missions celebrating or commemorating an event or a person or advertising a product (1D) may do more harm to the environment than good to the intended audience. The question may be addressed of what constitutes the benefit of mankind in this context.

Active measures (2) deal with removing of inactive objects from orbit. There are different methods depending on the altitude of the relevant orbit. In low orbits an object can be sufficiently decelerated by an inflated balloon. At higher orbits, a braking rocket pulse might be needed while in high orbits, such as the geostationary orbit, a reorbiting into disposal orbits beyond the belt of active satellites is the most economical solution. All these measures assume that the method of removal or disposal was decided upon before the launch and that the relevant devices are available on board the spacecraft. Some designers of spacecraft use such or similar measures but a systematic application of these measures will also require several years before they become effective.

Space debris and inactive satellites which are already in orbit can be removed either by direct contact or by remote action. Direct contact, in case it is permitted under space law, requires a spacecraft capable of collecting unwanted objects. This method may be used in rare cases of very valuable inactive satellites but would not be economical for small or worthless pieces of hardware. In the latter case (2D) remote action may have to be resorted to. A few papers on the subject already appeared in literature but some encouragement by a recommendation of the COPUOS would certainly speed up research of such methods.

From among the passive measures, the avoiding of collisions by evasive manoeuvres and the shielding of spacecraft are within the competence of launching and operating agencies. Possibly no international action is necessary. They have been listed here only for the sake of completeness.

The improving of the flow of information on trackable objects is the most important measure in this category. It requires a solution on an international basis. Information on the number, size, location and motion of space objects is essential for the protection of active spacecraft as well as for the application of any method of removal of unwanted objects. The only

intergovernmental source of information is the United Nations Register based on launching announcements by Governments made in conformity with the Registration Convention. The Register is, however, incomplete, the information becomes available far too late and the data in the Register are insufficient for computing positions and motions of space objects. A new system, possibly based on one or more available national systems, providing timely data for all trackable objects, would be extremely useful. A proposal for such a system might be discussed in the COPUOS and its Subcommittees, perhaps with the result that a launching agency, or a non-governmental organization, such as the IAF or COSPAR, assume the responsibility for collecting and disseminating such information to interested users.

GERMANY

[Original: English]

Space debris: review of work done in Germany

Introduction

The scientific/technical analyses of space debris problems were continued in Germany in 1991 (for 1990, see working paper continued in document A/AC.105/C.1/L.170), mainly at the Institute for Space Flight Technology and Nuclear Reactor Technology of the Technical University of Braunschweig (IFRR/TUBS) under contract from the German Space Agency (DARA). Some work was also done in cooperation with the companies DASA/ERNO and Jenoptik.

Another DARA contract was signed in 1990 with the Research Establishment for Applied Science (FGAN) to investigate physical characteristics of selected debris by use of radar data. The present paper provides a review of current work and the main results achieved.

I. SPACE DEBRIS MODELLING

Modelling of the space debris environment is essential for several reasons:

- To obtain knowledge of the population of non-trackable small objects (below 10 cm) and

- For all simulations of the possible further evolution of the environment, which have to serve as a basis for discussions of necessary changes in future space flight policies.

Within the scope of the ongoing research work, several areas have been identified containing uncertainties and weaknesses as to the basic assumptions of space debris modelling, e.g. the mass and the area-to-mass ratio

distributions of the fragments generated by explosions and collisions in Earth orbits. The influence of possible uncertain factors on the modelling results is being evaluated to assess the reliability of the modelling results. Further experiments in explosion and collision fragmentation are urgently needed, in addition to further research work in the field of modelling, to reduce the uncertain factors and hence to increase the reliability of the modelling results.

II. MODELLING OF SMALL PARTICLES IN THE MILLIMETRE AND 0.1 MILLIMETRE RANGE

The small particle debris flux reached today corresponds to about 5 impact/m^2 per year of particles larger than 0.1 millimetre at altitudes of 400 to 500 km.

This estimation is based upon the examination of material returned from space. Materials from the Solar Max satellite were brought back in 1984 and have been examined to determine the debris flux. The Long Duration Exposure Facility (LDEF) was recovered in January 1990 and is being studied. Preliminary results can be found in several publications, see [11], [12] and [13].

Both the Solar Max data and the LDEF data indicate this fairly high flux value of 0.1 millimetre debris. Since LDEF was returned nearly six years later than materials from Solar Max, this flux seems to be steady over a period of time. As these small particles have only a short orbital lifetime due to atmospheric drag, the continuous flux of small debris must have been produced by a steady process.

The earlier assumption [10] that the small particles in this size range would mainly be generated by collisions in space cannot explain this phenomenon because, fortunately, a steady process of repeated collisions has not yet started.

In the current model of IFRR/TUBS, not only collisions but also high-intensity explosions are taken into account. In the period from 1968 to 1989, 29 explosions in space are classified as being of high intensity. With 2 additional collisions, the 31 breakups are distributed over a period of time, in a manner that indicates a steady process generating small debris.

Based on numerical simulations of the 31 breakups, two databases for the millimetre and the 0.1 millimetre range, respectively, have been established. The millimetre database represents 100 million objects while the 0.1 millimetre database covers 80,000 million objects. To make computer simulation possible, only 84,000 sample objects have been selected for each database. The selection is conducted in such a way that the distributions of mass, semi-major axis and eccentricity are statistically represented.

These databases have been applied to predict the debris flux on LDEF [14], and the modelling results correspend positively with the observed data.

III. SPACE DEBRIS MEASUREMENTS

During 1991 a study was initiated to examine the capabilities of optical space debris observation. The main goal of this study is a concept that would permit the existing data gap [9] of space debris in the millimetre- to decimetre-size regime to be closed. Both ground-based and space-based telescopes operating in the visible and infrared wavelengths have been analysed, taking into consideration a number of relevant detection scenarios.

During the study, attention was focused primarily on two orbital altitude regions, i.e. 350-500 km (where manned space flight is performed) and the region of 800-1,000 km altitude, which is characterized by the highest object density. The results of the study so far can be summarized as follows:

- Optical detection and measurements of space debris in the above-mentioned altitude regions could make a substantial contribution to the urgently needed verification of space debris modelling.

- In the case of space-based measurements, an elliptical, sun-synchronous sensor orbit (e.g. 500 km x 900 km) operating at the day-night terminator seems to be appropriate (optimal object illumination, detection 24 hours a day).

- In the case of ground-based telescopes (modified) existing systems should be used.

- Concepts for data evaluation and space debris model upgrade are available.

- The technical concepts (instrumentation, infrastructure) are feasible, the anticipated performance (number of detections, detection rate, optical range etc.) meets the requirements.

IV. COLLISION CHAIN REACTION EFFECTS

At present, the space debris collision risk is probably dominated by fragments from the explosion of payloads and rocket upper stages in Earth orbits. In the future, interactive collisions between objects in Earth orbits may become the main source for the generation of fragments.

The total risk for a collision among an assumed current population of 85,000 objects above 1 cm is about 45 per cent annually. The collision risk estimation for the total destruction of the target object is presently in the order of about 7 per cent annually [1].

The larger fragments generated by such collisions should lead to the formation of an artificial debris belt as a result of a chain reaction. Analysis has shown that the current population in higher altitudes has

possibly already exceeded the critical level [1]-[5]. These results are consistent with investigations performed by NASA using totally different approaches [6].

Basically, the increase in collision risk will be proportional to the square of the number of objects in Earth orbits. But the larger objects, as the potential sources for the generation of a large number of collision fragments, are of crucial importance. Hence, it is important that the population of larger objects be limited within the next few decades. Therefore it is necessary to introduce fundamental changes in the way space flight activities are carried out: all objects brought into higher Earth orbits, where there is no self-cleaning effect of the Earth atmosphere, must be actively removed after the end of their mission, preferably by a propulsive deorbit device.

If it is not possible to limit the population of large objects in time, i.e. within the next 10 to 30 years, the only way of preventing a chain reaction after the critical population level has been exceeded is to reduce the population of large objects by active removal [7], [8] (see following chapter).

V. LIMITATION OF THE POPULATION BY ACTIVE REMOVAL

As has been discussed in the previous chapter, the debris population has to be limited to an uncritical level as far as fragment generation due to collisions is concerned. Preventive measures, which are preferable, have already been described in detail in document A/AC.105/C.1/L.170. Another option for limiting the population is active removal, which is much more difficult and expensive. However, if preventive measures are not sufficient or if they are not introduced in time, active removal will be the only way to avoid a collision chain reaction.

Active removal is only economical

- for larger objects, because they are the potential sources for the generation of a large number of fragments following collisions;

- at altitudes between 700 and 2,000 km, where the chain reaction will be triggered and the objects have very long lifetimes;

- on a large scale (several thousands); otherwise there will be no appreciable effect.

A fundamentally new strategy for economical removal with the help of space tethers called TERESA (TEthered REmover SAtellite) is under investigation [7], [8]. This strategy is feasible through the use of techniques expected to be available in the near future.

VI. SHIELDING AND IMPACT ANALYSES

While the impact risk of centimetre-sized particles is still minor for small satellites and short mission times, it becomes unacceptably high for large manned vehicles and long mission durations, such as the pressurized modules of space stations. These have to be protected against debris smaller than a few centimetres by heavy shielding.

In Germany there are many activities in the field of meteorite/debris protection measures. Studies of concepts for meteorite and debris protection systems for manned spacecraft (e.g. COLUMBUS) are performed under ESA contract by MBB/ERNO. These studies include hypervelocity impact testing (Ernst-Mach-Institut, Freiburg, Batelle Frankfurt) of several shielding configurations, as well as the development of corresponding design tools.

In IFRR/TUBS, double wall shielding concepts are being analysed and a computer code, named DAMAGE, has been developed. By means of the DAMAGE code the shielding can be designed to meet the required safety level. Also, spectral analysis of penetration flux versus impact velocity or particle diameter can be conducted, which is very effective for the verification of existing penetration functions.

VII. PHYSICAL CHARACTERISTICS OF ORBITAL DEBRIS

As mentioned above, explosions and collisions in space are the major source for orbital debris. The debris fragments pose a hazard to large spacecraft designed to operate for long periods of time. A contract from DARA was signed with the Research Establishment for Applied Science (FGAN) in 1990 to investigate physical characteristics of selected space debris by use of radar data. The objective of a corresponding NASA/FGAN joint research investigation is to characterize and compare debris shapes, sizes, intrinsic motion, masses, and orbital lifetime from different explosions.

FGAN radar systems (narrowband as well as high-resolution radars) have been used to measure a collection of 16 different larger debris objects. Narrowband radar signatures were analysed and radar images have been computed [15], [16] to get first results about shape, size, attitude, and mass. Methods to assess orbital lifetime, ballistic coefficient, and drag factors of space objects were developed. They have been tested with FGAN radar data stemming from observations of decaying spacecraft [17], [18], [19].

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UKRAINE

[Original: Russian]

Although to date the Ukraine has not conducted scientific research on space debris, Ukrainian scientific institutions possess a number of methods of locating, and determining the exact coordinates of, large remains of space objects.

The Main Astronomical Observatory of the Academy of Sciences of the Ukraine has developed, prepared and put into operation on a wide-angle astronomical camera special equipment for observing geostationary satellites capable of determining the coordinates of objects with a brightness equal to or greater than stellar magnitude 14 to an accuracy of 0.3-0.6 arc-seconds.

An improved set of equipment has been designed, which would make it possible to locate fragments of space objects ranging in size from 10 cm and above.

In cooperation with a number of research institutes, the Main Astronomical Observatory of the Academy of Sciences of the Ukraine developed and tested an infrared television system operating in atmospheric transmission windows of 2.2 and 3.5 micrometres. The use of such equipment mounted on ground-based telescopes makes it possible to locate large fragments of structures of spacecraft in outer space.